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CHARACTERIZATION OF VESSEL WASTES IN DULUTH-SUPERIOR HARBOR

Garth D. Bumtz, et al

Environmental Quality Systems, Incorporated

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Five wastes from United States, Canadian, and foreign commercial vessels were studied at the Duluth-Superior Harbor during late 1973: bilge water, non-oily ballast water, sewage, garbage/refuse, and dunnage. Vessels generate bilge water at about 6,650 liters/hour with an average oil content of about 225 milligrams/liter. Waste oil which is apparently discharged to bilges (about 600 grams/hour) appears more consistent than either of these two parameters. Bilge water is a substantial pollution problem: on the average about 40 liters (10 gallons) of oil may be discharged during each day a vessel spends in the harbor. Although containing about twice the common water quality contaminants as the harbor waters, ballast water is not a significant environmental problem. Large quantities are, however, discharged: about 9,000 metric tons/visit by lake and bulk carriers. Sewage is apparently generated onboard vessels consistent with accepted design rates (100 gallons/man/day). Although largely under control, sewage may impact wastewater treatment facilities by being significantly stronger than typical municipal wastewaters. Chemical additives commonly found in vessel sewage may adversely affect wastewater treatment facilities and harbor receiving waters.

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FOREWORD

Man and his environment must be protected from the adverse effects of pesticides, radiation, noise and other forms of pollution, and the unwise management of solid waste. Efforts to protect the environment require a focus that recognizes the interplay between the components of our physical environment--air, water, and land. The National Environmental Research Centers provide this multidisciplinary focus through programs engaged in

- studies on the effects of environmental contaminants on man and the biosphere, and
- a search for ways to prevent contamination and to recycle valuable resources.

This report serves to quantify some of the pollution problems associated with vessels in the Great Lakes including oily bilge water, non-oily ballast water, and garbage/refuse. The data contained herein provides an initial base for pollution control and abatement efforts.

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National Environmental
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ABSTRACT

Five wastes from United States, Canadian and foreign commercial vessels were studied at the Duluth-Superior Harbor during late 1973: bilge water, non-oily ballast water, sewage, garbage/refuse and dunnage.

Vessels generate bilge water at about 6,650 liters/hour with an average oil content of about 225 milligrams/liter. Waste oil which is apparently discharged to bilges (about 600 grams/hour) appears more consistent than either of these two parameters. Bilge water is a substantial pollution problem: on the average about 40 liters (10 gallons) of oil may be discharged during each day a vessel spends in the harbor.

Although containing about twice the common water quality contaminants as the harbor waters, ballast water is not a significant environmental problem. Large quantities are, however, discharged: about 9,000 metric tons/visit by lake and bulk carriers.

Sewage is apparently generated onboard vessels consistent with accepted design rates (100 gallons/man/day). Although largely under control, sewage may impact wastewater treatment facilities by being significantly stronger than typical municipal wastewaters. Chemical additives commonly found in vessel sewage may adversely affect wastewater treatment facilities and harbor receiving waters.

Foreign vessel garbage/refuse will be more difficult to incinerate than municipal solid wastes. Water content is higher (about 40 weight percent) and the total wet heat value lower (about 2,400 calories/gram). The average garbage/refuse generation rate was found to be 3.6 kilograms/man-day.

Foreign vessel dunnage was not available in large enough quantities during the field study to permit detailed characterization. Observations indicated, however, that lumber sizes and metal content vary considerably.

In general, vessels generate wastes with extreme variability. Orders of magnitude differences in both quantity and quality are common.

This report was submitted in fulfillment of Grant No. R-802772 by Environmental Quality Systems, Inc., Rockville, Maryland, for the Seaway Port Authority of Duluth, Duluth, Minnesota, under the sponsorship of the Environmental Protection Agency. Work was completed as of December 1973.

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The Western Lake Superior Sanitary District (WLSSD) provided continuing assistance throughout the course of the project. Mr. Gary Baker, Supervisor of WLSSD's Duluth Sewage Treatment Plant Laboratory, did a commendable job in providing analytical services under sometimes trying conditions. Dr. W. Freiberger, Director, and his staff, of the Michigan Technological Institute, School of Mining, Research Center at Houghton, Michigan, comminuted garbage and prepared samples under very tight time schedules.

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In general, the project staff wishes to thank all the people and organizations of Duluth, Minnesota and Superior, Wisconsin, who assisted in completion of the study. Their cooperation was outstanding and a credit to the Duluth-Superior community.

Finally, appreciation must be extended to Mr. William Librizzi, the Project Officer from the U. S. Environmental Protection Agency, for assisting in every possible way during the study. He and the analytical staff at the Industrial Waste Treatment Research Laboratory expeditiously provided oil analyses of the wastewater samples gathered, often in large numbers.

SECTION I

CONCLUSIONS

The following conclusions are apparent based on the Seaway Port Authority of Duluth/Environmental Quality Systems, Inc. study of commercial vessel waste generation at Duluth-Superior Harbor:

(1) In general, high vessel-to-vessel variability was a characteristic of all the wastes studied. Variations of 2 or 3 orders of magnitude are not uncommon for both quantity and quality. Such variability is due basically to variations in operation and design from ship-to-ship. The average vessel waste parameters developed from the field data cannot be reliably applied to a single or small numbers of vessels. For example, bilge water generation rates and oil concentrations varied, as determined in the study, from 5 to 26,000 liters per hour and 0.4 mg/L to 84 percent by volume respectively. This, however, does not reduce the value of the averaged data used in assessing overall impact or in comparing classes of vessels as is done below.

(2) Bilge water is the most significant (environmentally) vessel waste being generated at the Harbor. According to the survey, the average vessel generates 6,650 liters or 1,760 gallons of bilge water per hour. This wastewater contains, on the average, about 225 milligrams of oil per liter and 1,200 milligrams per liter of COD.

(3) Recirculation (recycle) sampling of bilge water using a portable pump is preferred over submersion (grab) sampling; however, when possible, samples should be taken directly from bilge pump effluent.

(4) Diesel powered vessels generate bilge water with about twice the oil content as steamers (295 versus 140 milligrams per liter).

(5) Vessels over 20 years in age generate bilge water at about twice the rate as younger vessels (10,000 versus 5,000 liters per hour).

(6) Canadian, United States and foreign flag vessels were found to have increasingly poor quality bilge water, in that order; foreign flag, Canadian and United States vessels were found to generate increasing amounts of bilge water, again in that order.

(7) Waste oil which is apparently discharged to bilges (on the average 660 grams per hour) appears to be a less variable parameter than either genration rates or oil content.

(8) Although vessel operators attempt to minimize their bilge water

discharge while in the Duluth-Superior Harbor, these large quantities of highly contaminated water must eventually be discharged, usually into the Great Lakes.

(9) The average ore and bulk carrier discharges about 8,800 metric tons (2,300,000 gallons) of non-oily ballast water per visit to the Duluth-Superior Harbor; this quantity is 75 percent of total ballasting capacity.

(10) For the common water quality parameters, non-oily ballast water apparently has anywhere from 1 to 10 times the concentrations as the natural harbor waters; this is highly dependent on the particular vessel being considered.

(11) The quality of ballast waters appears to degrade only slightly in transit to Duluth-Superior.

(12) Compared to other pollution control and environmental problems, non-oily ballast water does not appear to be a major concern at the Duluth-Superior Harbor.

(13) Sewage is apparently generated onboard vessels visiting Duluth-Superior in line with accepted literature and design values: 380 liters or 100 gallons per man per day for combined wastes (including galley, laundry, shower, lavatory and sanitary wastewaters) and 95 liters or 25 gallons per man per day for sanitary wastes.

(14) Vessel sewage is highly concentrated: average BOD, suspended, and settleable solids of 750, 1,800, and 1,600 milligrams per liter respectively.

(15) Although sewage appears to be reasonably well controlled onboard vessels, its strength, chemical and oil content could produce severe problems for small shoreside wastewater treatment facilities which accepted and attempted to treat same.

(16) Garbage/refuse is generated onboard foreign vessels at fairly high rates: 3.6 kilograms or 8 pounds per man per day; no dependence was found on vessel nationality.

(17) Vessel garbage/refuse contains large quantities of food (62 percent) and glass/ceramic (12%) wastes and relatively small amounts (8.5%) of paper.

(18) Incineration (or other disinfection) of foreign garbage/refuse may prove difficult due to high water content (about 40 percent) and low total heat value (2,400 calories per gram).

(19) Due to the scarcity of dunnage in the harbor during the study period, little can be concluded on this waste other than that it contains a large size range of lumber and varying types of metal in relatively small amounts.

SECTION I

CONCLUSIONS

The following conclusions are apparent based on the Seaway Port Authority of Duluth/Environmental Quality Systems, Inc. study of commercial vessel waste generation at Duluth-Superior Harbor:

(1) In general, high vessel-to-vessel variability was a characteristic of all the wastes studied. Variations of 2 or 3 orders of magnitude are not uncommon for both quantity and quality. Such variability is due basically to variations in operation and design from ship-to-ship. The average vessel waste parameters developed from the field data cannot be reliably applied to a single or small numbers of vessels. For example, bilge water generation rates and oil concentrations varied, as determined in the study, from 5 to 26,000 liters per hour and 0.4 mg/L to 84 percent by volume respectively. This, however, does not reduce the value of the averaged data used in assessing overall impact or in comparing classes of vessels as is done below.

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(5) Vessels over 20 years in age generate bilge water at about twice the rate as younger vessels (10,000 versus 5,000 liters per hour).

(6) Canadian, United States and foreign flag vessels were found to have increasingly poor quality bilge water, in that order; foreign flag, Canadian and United States vessels were found to generate increasing amounts of bilge water, again in that order.

(7) Waste oil which is apparently discharged to bilges (on the average 660 grams per hour) appears to be a less variable parameter than either genration rates or oil content.

(8) Although vessel operators attempt to minimize their bilge water

SECTION II

RECOMMENDATIONS

Based on the conclusions and the more detailed analyses in the main body of the report, the following are recommended:

(1) Vessel bilge water wastes should be controlled more stringently in the Duluth-Superior Harbor, and in the Great Lakes as a whole. Most bilge water being discharged is more contaminated than presently allowed by law and regulations. That which is not is due mainly to dilution (an unacceptable control technique in most instances). Monitoring by appropriate governmmental agencies plus advanced bilge water treatment will probably be necessary for this control.

(2) Until proven a more significant contributor to water pollution problems, non-oily ballast (at the Duluth-Superior Harbor) should be the subject of only limited control and regulation. Vessel owners and operators should be made aware, however, that "non-oily" ballast can be a noxious waste if not handled properly.

(3) Although vessel owners and operators appear to be controlling sewage onboard their vessels, municipal wastewater treatment facilities must be wary of casually accepting such wastes. They are highly contaminated and often contain chemical additives. More definitive work should be done on characterizing vessel sewage and its possible impact on wastewater treatment plants.

(4) Facilities for foreign vessel garbage/refuse disposal or disinfection should be designed to handle the lower total heat values and higher water contents determined in this study.

(5) Foreign vessel dunnage should be more completely characterized before design and demonstration of advanced disposal and disinfection facilities is initiated.

(6) Systems for the control or treatment of wastes from a single or small number of vessels should be designed using data for that particular vessel(s). High variability in characteristics must be considered an (or, possibly, the) important property of vessel wastes.

SECTION III

INTRODUCTION

Vessel pollution in harbors is a much discussed but not very well defined environmental problem.

Bilge waters from both fresh water and ocean going vessels are known to be oily, and their discharge to receiving waters known to be polluting. However, the magnitude and variability of the problem, effects of propulsion system, dependence on vessel age and nationality, etc., are not well known, if at all. Furthermore, means to estimate the quantity and quality of bilge water are not readily available. Such means must be forthcoming if the Nation's fleet, particularly in the Great Lakes, is to be outfitted with effective bilge water treatment devices.

A similar state of affairs exists for ballast water discharges. Although several studies have been conducted to characterize oily ballast water from tankers, no information is available on the nature of ballast water discharges from other than oil tankers. "Non-oily ballast" may also be contaminated and present a threat to the environment. Although contamination with hydrocarbons is bound to be less, other pollutants (suspended solids, biological oxygen demand, coliform bacteria, etc.) may be present in high concentrations, especially in cases where ballasting may occur in polluted waters (e.g., certain ports on the Great Lakes). Due to the large quantities of water involved, the pollution potential of non-oily ballast water should be assessed.

Although quantity and quality data are available from the literature on vessel sewage, little of this relates directly to the high variability of conditions actually encountered onboard vessels. Existing sources are primarily data from marine sanitary system manufacturers and studies of various treatment concepts under controlled conditions. Little information can be found which addresses the problems of overloaded systems, chemical additives, high waste concentrations, wastes from recycle systems, holding tanks which have gone septic, etc. Such information could be very valuable in determining the suitability of shoreside wastewater treatment for existing vessels.

Garbage/refuse from vessels is often assumed to be similar to that generated in municipalities. Data collected by the U. S. Navy, however, indicates that this assumption may not be valid. Addition of household and industrial garbage/refuse generation rates does not exactly model conditions onboard vessels: (1) dietary habits are perturbed by shipboard environments, (2) disposable materials are often used due to limitations on laundry, dishwashing and other cleaning services, (3) extensive use of readily available water can lead to very wet solid wastes, (4) solid wastes from foreign vessels may be infested and (5) used materials,

which would not be discarded onshore, are often added to the solid waste stream. These differences make more careful characterization of commercial vessel garbage/refuse generation important, especially for larger ports.

Dunnage (waste "wood" previously used for supporting, protecting and holding cargo) can be an especially large problem at ports. Disposal of this material is in itself troublesome. Foreign dunnage may be infested with agricultural pests adding to the basic disposal problem by requiring disinfestation. Size variations of the lumber comprising dunnage plus substantial amounts of contained metal make characterization important. For instance, in a particular load of dunnage anywhere from 12 foot lengths of 10 x 10's to short lengths of lathing may be found as well as upwards of one percent by weight metal in the form of nails, staples, bolts, strap, wire and cable.

The remaining pages of this report describe a study of the vessel wastes mentioned above at the Duluth-Superior Harbor on Lake Superior. This study was conducted for the Seaway Port Authority of Duluth under a grant from the U. S. Environmental Protection Agency. In Section IV the aim of this particular study is described briefly. Section V presents a summary of the sampling and analytical techniques which were used in the study. Section VI presents the data which was gathered during late 1973 at the Duluth-Superior Harbor. Section VII is a brief analysis of the study accompanied by a brief discussion of same.

SECTION IV

PROJECT DESCRIPTION

The primary thrust of the vessel waste study at the Duluth-Superior Harbor was in collecting and analyzing waste samples to characterize bilge water, non-oily ballast water, sewage, garbage/refuse and dunnage. Data was also collected on the magnitude of waste generation. The latter tends to be a very complex and expensive proposition, especially for liquid wastes. Therefore, most generation data, as well as information on operations, came from surveys and interviews of vessel crew members and service companies. After an initial two week set-up and shakedown period under the direction of the project supervisor, the project's field engineer and technician gathered all vessel and operations data, took selected samples of the various wastes, and prepared the latter for analysis; in some cases (i.e., for garbage and dunnage) all or part of the analyses were performed by this field team. Extensive cooperation from vessel and service owners and operators was required for the successful completion of these tasks.

Bilge water was the waste studied most thoroughly during the project. Initially, 25 vessels were to be sampled; this was increased to 35 and, in the end, 37 were actually sampled. Every effort was made to consider a wide spectrum of vessels: type (bulk, lake or general cargo carrier), nationality, propulsion system, and age. Several different techniques for sampling bilge water were used; comparison of the results for these different techniques provides a necessary foundation for any future sampling work as well as means for estimating sampling reliability.

Bilge (as well as ballast and sewage) water samples were collected with the assistance of vessel agents, owners and operators. Usually, the field engineer made an appointment to board a particular vessel, interview the chief engineer and take samples. The interview provided basic information on the vessel and data necessary for estimating waste generation rates. When possible, the engineer's log book was used as a basic data source. After the field engineer and technician set up for sampling onboard a vessel, matters became quite routine and interviews could be conducted concurrently. After sampling, about an hour was usually required to pack up equipment and return to the Port Authority offices; here, samples were acidified (except those used for biochemical oxygen demand and coliform determinations) and either refrigerated or transported to the Duluth Sewage Treatment Plant laboratory. Samples requiring total organic carbon, oil and metals analyses were shipped by air freight to the Edison Water Quality Laboratory in New Jersey. Easy access to the bilges onboard vessels made bilge water sampling relatively easy. Dry bilges, lack of adequate power for the sampling pump, and lack of access prevented sampling at times as did equipment failures.

When required, non-oily ballast water samples were taken using a Kemmerer sampler; either the engineer or technician did this while the other took bilge water samples. These samples were also preserved and routed to the appropriate analytical facility. Since manhole access to ballast tanks is typical, grab sampling ballast water was usually easy. Originally, 5 ballast water samples were to be taken; this number was eventually raised to 10 and, finally, 11 (plus 2 harbor samples) were collected and analyzed. Non-oily ballast water was not studied in great detail. The point of the study was basically to assess the possibility that a pollution problem exists.

Sewage samples were generally difficult to obtain. With the assistance of ship's engineers the field engineer generally had to open holding tanks or bleed samples from pumps. There was no routine way to do such sampling as is indicated in the report section which follows. When required, sewage samples were taken concurrently with bilge water samples. Six samples were required and eventually taken.

Both foreign vessel garbage/refuse and dunnage were studied relatively independently of actual vessel operations. This was possible only through the cooperation of the disposal company at the harbor, Bayfront Marine Services. The project required weighing approximately 25 percent of the foreign garbage offloaded at the harbor; this was done primarily by disposal company employees using a truck scale. Garbage analyses were performed by the field crew (hand sorting into basic categories) with assistance from others. Combustible wastes had to be transported to Michigan for grinding and mixing; this required a special permit from the U. S. Department of Agriculture as well as careful handling and packaging due to possible contamination. Samples prepared in Michigan were delivered to a laboratory in Minneapolis, Minnesota for water content and total heat value determinations. The field engineer was in charge of this operation. Four samples from 2 vessels were subjected to such detailed preparation and analysis. In a similar fashion, dunnage (when available) was weighed using a truck scale; size analyses were determined by measuring and counting, and metal content by separating and weighing. Although 2 loads of dunnage were scheduled for thorough analysis, the second load never materialized.

SECTION V

SAMPLING AND ANALYTICAL TECHNIQUES

Although the samples of vessel wastes gathered at Duluth-Superior Harbor could be analyzed using fairly standard techniques, the sampling itself was by no means "standard". That is, there were no widely accepted procedures for sampling the vessel wastes of interest. These should eventually be developed if widespread agreement upon and resolution of the vessel waste problem is to be achieved.

The following paragraphs describe the sampling and analytical procedures used for the five waste categories. No attempt is made to present standard techniques in detail.

BILGE WATER SAMPLING

Bilge water was the most difficult waste for which to collect samples. Since "small" volumes of water spread over a relatively large area are usually involved, some care must be taken to simulate bilge pumping during sampling; dipping (grabbing) samples is probably not acceptable. In general, obtaining representative samples must be a primary aim. Analysis of bilge water samples, on the other hand, can, to a large extent, be according to "standard methods" or procedures acceptable to EPA.

Several techniques were used for sampling bilge water from vessels. The primary method was to recirculate the water located in the bilge area of the engine room. A portable 40 gpm pump (Montgomery Ward, Model SBN 25415) was used for recirculation. The suction side of the pump was placed near the bilge water intake for a ship's bilge pump. This intake is almost always located in the aft section of the engine room below the propeller shaft. The water withdrawn at the intake was discharged in the fore section of the engine room. Discharge was to a dry area or to relatively stagnant water while submerged. This technique was used to simulate the ship's bilge pump which causes circulation mixing of floatables and settleables as well as actual discharge of such materials. In the pumping process, a portion of floating oil and suspended material is usually withdrawn with the water. The recirculation method can be used since the engine room bilge is a common area; that is, it is usually not divided by bulkheads. Water can, therefore, flow freely from fore to aft in the engine room.

Note that the recirculation technique can be used only under specific conditions. The following can prevent using this method:

(1) Shallow bilge water (10 or so centimeters), pump surging.

(2) A "dry" bilge.

(3) An inaccessible bilge water sump.

(4) Absence of 110 volt, 60 cycle, AC power in the engine room.

(5) Too great a vertical lift for the portable pump used.

(6) Impossibility of obtaining a representative sample (e.g. due to extreme bulkheading of the engine compartment), and

(7) The availability of an alternative sampling technique which will provide a more representative sample.

The recirculation method was tested by taking samples over a period of pumping time to ascertain the effects of recirculation. Samples could usually be confidently taken after 15 or 30 minutes of recirculation.

The second bilge water sampling technique was submersion of a sample bottle into the bilge water; this is a grab sampling procedure. A stoppered bottle was submerged, the stopper was removed and replaced once the bottle was filled while remaining submerged. Sampling depth varied from several centimeters to about a meter depending upon the amount of water in a bilge and the apparent thickness of the layer of oil floating on the water. The latter was, in general, difficult to circumvent other than by taking repetitive samples.

The submersion technique has limitations similar to those above for recirculation. Limiting conditions are as follows:

(1) Bilge water is not deep enough for submersion,

(2) Inaccessible bilge water sump (no water elsewhere),

(3) Too deep an oil/water layer to allow a representative sample, and

(4) Another sampling technique would be more representative.

A combination of sampling techniques was sometimes used on a given vessel. Using more than one provides a basis for comparison of the various methods. Furthermore, the "best" can possibly be determined by using and comparing different methods of sampling.

The third sampling technique was sampling directly from the ships bilge pump. Many bilge pumps were equipped with a valve or a pressure gauge port where a sample could be taken. The samples were taken either directly from the valve or port or by shunting discharge water to the bilge area. Removal of a pipe coupling, pressure gauge line, or other breaking of a discharge line were also used. Variations in sampling from the pump are dependent upon the type of pump(s), accessibility, and the general configuration of the bilge area. This is, obviously, the preferred technique for obtaining bilge water samples.

BALLAST WATER SAMPLING

Ballast water can also be analyzed using mainly standard methods. Since ballast water is deep and a relatively stagnant volume, sampling can be done using state-of-the-art procedures (e.g., bottle type samplers). Note, however, that this is for non-oily ballast; oily ballast must be sampled much more carefully since oil/water stratification occurs readily in ballast tanks.

Ballast samples were taken using a 3.8 liter (one gallon) Kemmerer sampler. Ballast tanks were accessible through manholes on either the weather deck or the tunnels adjacent to the cargo holds, depending on the type vessel and its general configuration. Composite samples were made from samples taken at various depths in the tank. Given sufficient water in a tank, the depths sampled were about one foot from the bottom, at the middle of the tank, and about one foot from the surface. Ballast tanks were typically 26 feet deep; therefore, a typical composite sample consisted of equivolumetric samples from levels of 1, 13 and 25 feet.

SEWAGE SAMPLING

Sewage is also a very difficult waste to sample under field conditions. Sample ports were not generally observed on either sewage holding tanks or treatment systems. Without cutting into piping, samples must generally be taken through manholes, drain pipes, or petcocks on wastewater pumps. Again, sample analyses require only standard wastewater procedures.

Sewage samples were taken from holding tanks on ocean-going vessels and U. S. and foreign lakers. No single technique could be established due to ship-to-ship variations in sewage handling systems and holding tanks. If possible, a grab sample was taken after internal recirculation of sewage in a holding tank. However, accessibility often necessitated alternative techniques. For instance, samples were taken from a valve on a discharge line or directly off a wastewater pump. Several systems observed were completely inaccessible while others would not allow sampling since the wastewater would have had to been illegally discharged.

GARBAGE SAMPLING

Sampling garbage was also a difficult problem. Since only two containers of garbage were thoroughly analyzed, the results cannot be applied generally. Selection of garbage for weighing was done by the field crew on essentially a random basis with assistance of the disposal service operators. Analyses were basically standard with the one exception being in sample preparation: completely ideal garbage comminution equipment was not available and a make-shift arrangement was, therefore, used.

The garbage was weighed from about one of every 4 foreign flag vessels. The disposal service personnel in charge of garbage collection did this weighing when possible. Due to dock inaccessibility, some vessel garbage is transported via boat, unloaded at the garbage facility and incinerated;

this garbage could not be weighed. Also, some loads were not very large so garbage from more than one ship was loaded onto a single truck. Other constraints such as time, availability, high levels of activity, weather and operating personnel prevented maintaining a consistent schedule for weighing garbage. However, approximately 25% of all loads collected during the 2.5 month field program by the local contractor were weighed.

The two containers of garbage that were sorted, comminuted and analyzed were selected (in consultation with one of the disposal operators who has had several years experience in handling garbage from foreign flag vessels) as being "typical". Two 55 gallon containers were sorted at the site of the garbage incinerator, separated into gross solid waste categories, bagged, weighed, comminuted to a homogeneous mixture and analyzed at a local laboratory.

DUNNAGE SAMPLING

A typical batch of dunnage consisted of more than one truckload. An attempt was made to weigh every truckload; however, due to the time and personnel involved (longshoremen, ship's crew and several employees of the local contractor), this was not possible. However, 50% of the truckloads were weighed. Size and metal content analyses were made for two truckloads of dunnage. Due to sample limitations (i.e., dunnage from only one vessel during the 2 month study) weights and analytical results cannot be generalized.

WASTEWATER (BILGE, BALLAST, AND SEWAGE) ANALYSES

Analyses for wastewater samples (bilge, ballast and sewage) were, in large measure, carried out according to "Standard Methods for the Examination of Water and Wastewater, 13th Edition". Most analyses were performed at the Duluth Sewage Treatment Plant Laboratory, which is now owned and operated by the Western Lake Superior Sanitary District (WLSSD). The tests performed were as follows:

1) Biochemical Oxygen Demand, 5-day (BOD_5)

2) Chemical Oxygen Demand (COD)

3) Suspended Solids

4) Volatile Suspended Solids

5) Settleable Solids

6) Total Phosphorus

7) pH

8) Total Coliform

9) Oil

10) Total Organic Carbon

11) Atomic Absorption for Metals

Brief discussions of each of these analyses are presented in the Appendix to this report.

GARBAGE ANALYSES

Samples of garbage consisted of two 55-gallon drums, each weighing 220 to 300 pounds. It is at best impractical to separate, measure, and weigh all the garbage that is unloaded from a single ship, let alone an entire shipping season's garbage. In a recent study ("Analysis of Solid Waste Composition" by Carruth and Klee of the Public Health Service) 200 pound samples were shown to yield statistically valid results for the composition of garbage. A major possibility is that samples from more than two loads of garbage should be analyzed, however, to characterize garbage generation for the entire harbor. This same study listed nine standard garbage/refuse component classifications; these are:

1) Food waste

2) Paper products

3) Textiles

4) Wood

5) Plastic, rubber, and leather

6) Metals

7) Glass and ceramics

8) Ash rocks and dirt (inerts)

9) Garden waste

Note that garbage/refuse from foreign vessels is subject to the quarantine restrictions of the U. S. Department of Agriculture. That is, transport of such material must be under very controlled conditions. This is adequately illustrated in the following paragraphs.

Upon receipt, the contents of a sample drum were dumped onto a 20 foot plastic tarp. The waste was then hand sorted into the nine categories (if applicable). Once the segregation of the waste was completed, waste from each category was placed in a separate plastic garbage bag which was appropriately labeled. This procedure was then repeated for the second sample drum. The bags of waste and containers in which they were placed

were then sealed by a representative of the U. S. Department of Agriculture.

On the following day, the sealed samples were transported to the Michigan Technological Institute Mining Research Center at Houghton, Michigan. Each component bag was weighed and the necessary seal broken by a representative of the Michigan Department of Agriculture. The combustible portion of the waste (i.e., food waste, paper, textiles, plastic, and wood) was then ground in a hammermill with a 1/4 inch screen. However, large quantities of textiles and plastics could not be comminuted into a homogenous sample; they were, therefore, left out of the sample and later accounted for by estimating their effects. Therefore, the homogenous sample that was eventually analyzed consisted primarily of food waste, paper products, and wood, with only minor amounts of textiles and plastics. The overall sample was mixed and split (cut) by hand and two one quart samples were withdrawn for each 55 gallon drum of garbage/refuse processed. The ground garbage was returned to the bags and containers, resealed by the Michigan Department of Agriculture, and returned to the disposal facility at Duluth.

The one quart garbage samples were frozen at Duluth until they could be delivered to the Twin Cities Testing Laboratories, Inc. at Minneapolis, Minnesota. This laboratory determined moisture contents and heat values for a sample from each of the 55 gallon drums. These analyses were conducted substantially in accord with the standard procedures as presented in "Methods of Solid Waste Testing" by the U. S. Environmental Protection Agency, 1973. Such test results can be used to estimate ultimate disposal requirements; for instance, the amount of water which must be evaporated and heat of combustion supplied by the garbage itself can be estimated.

DUNNAGE ANALYSES

Dunnage was weighed immediately using a truck scale and isolated at the disposal site for further analysis prior to burning. Dunnage was measured using an 8 foot long by 12 inch wide by 12 inch deep jig. Individual pieces of lumber were placed on the jig and their dimensions recorded. Prior to measurement, all metal (e.g., straps, cables and nails) was removed and weighed to the nearest pound. After the size distributions had been determined, the dunnage was burned by the disposal service operators in line with their standard procedures. Dunnage from foreign vessels is also subject to quarantine regulations. Size analyses and composition estimates should be useful in designing systems for incineration or shredding and disinfestation of dunnage.

SECTION VI

SURVEY AND ANALYTICAL RESULTS

Previous sections have described the study in general as well as the sampling and analytical techniques used. This report section is in essence a tabular presentation of the results of the vessel surveys, sampling and analyses. Only brief descriptions which serve to explain the various tables are provided. The data presented is largely self-explanatory; obvious anomalies are, however, discussed briefly.

The study results are presented below in the same order used in previous discussions: bilge water, ballast water, sewage, garbage and dunnage, respectively.

BILGE WATER

Table 1 summarizes the vessel survey data for bilge water. This data was solicited from vessel operators to (1) characterize particular ships and (2) develop estimates of bilge water generation. The first row identifies the bilge water samples taken from the particular vessel in question. The second row lists the vessel type. General cargo vessels and tankers were not present in large numbers during the late 1973 season at Duluth-Superior. Lake and bulk carriers are similar although the latter are used for both bulk and general cargo and are often ocean going. Although only the broad categories of United States, Canadian and foreign vessels are of much practical use, the third line in Table 1 presents a detailed identification of vessel nationality; note that the term "nationality" refers to the predominant home origin of the crew. Row 4 describes the general nature of the vessel's propulsion systems. Although steam turbine and other steam driven vessels are differentiated on the table, for purposes of bilge water characterization they should probably be considered together. Vessel age in row 5 is self-explanatory although it is somewhat surprising that 3 crews were unable to supply a vessel age.

Row 6 of Table 1 lists probable bilge water sources; these were determined through interviews with vessel engineers and inspection. Under the bilge water sources is a listing of the number of bilge water pumps on-board the vessel. The frequency with which bilges are pumped is indicated in row 8. These frequencies, as well as the information in the following 2 rows, were obtained from ship's logs or by interviewing operating engineers. At best pumping frequencies are as scheduled while at worst they are educated guesses; no entry in row 8 indicates that a vessel's crew was unwilling to hazard an estimate of pumping frequency. Row 9 indicates the volume of bilge water discharged during each pumping activity; these numbers were either supplied by the vessel engineers or calculated on the basis of pumping duration (row 10) and bilge pump capacity. In some cases

Table 1. BASIC VESSEL AND RATE DATA FOR BILGE WATER

Bilge Sample Number	1-3	4	5	6-8	9-11	12	13,47
Vessel Type	Lake Carrier	Bulk Carrier	Bulk Carrier	Bulk Carrier	Lake Carrier	Lake Carrier	Bulk Carrier
Vessel Nationality	U.S.	Armenian	German	Canadian	U.S.	U.S.	Canadian
Propulsion System	St.Turb.	Diesel	Diesel	St.Turb.	St.Turb.	Steam	Diesel
Vessel Age (yrs.)	19	4	-	14	24	50	5
Bilge Water Sources	pumps, condensors, gauges	engine, pumps	engine, pumps, sanitary	shaft, pumps, cooling water, sanitary	shaft, bearings	shaft, pumps	condensate
Bilge Pumps, Number	2	3	1	3	1	1	2
Pumping Frequency	-	automatic	1/week	automatic	1/40min.	4-5/4hrs.	1/4hrs.
Bilge Water Pumped, m^3 (gal.)	-	-	18(4800)	-	0.3(80)	-	-
Duration of Pumping	-	-	2hrs.	-	2min.	3-4min.	5-10min.
Apparent Generation Rate: liters/hour (gallons/hour)	- -	- -	108 (29)	- -	450 (120)	- -	- -

Table 1 (Continued). BASIC VESSEL AND RATE DATA FOR BILGE WATER

Bilge Sample Number	14	15,16	17	18,19	20-26	27
Vessel Type	Lake Carrier	Bulk Carrier	Bulk Carrier	Lake Carrier	Bulk Carrier	Lake Carrier
Vessel Nationality	U.S.	British	Canadian	U.S.	British	U.S.
Propulsion System	St.Turb.	Diesel	St.Turb.	St.Turb.	Diesel	Tr.Expan.Steam
Vessel Age (yrs.)	20	4	23	28	4	67
Bilge Water Sources	pumps, shaft seal, condensors	engine, ballast pumps	shaft,condensors, pumps, shaft seal, cooling water	pumps, shaft seal	shaft seal, ballast pumps, condensation	shaft seal, cooling water, condensation
Bilge Pumps, Number	1	2	2	2	1	1
Pumping Frequency	1/20 min.	1/2days	automatic	1/4hrs.	1/day	continuous
Bilge Water Pumped, m^3 (gal.)	7.6 (2000)	-	-	20 (5200)	3.4 (900)	-
Duration of Pumping	4-5min.	-	-	10min.	10min.	-
Apparent Generation Rate: liters/hour (gallons/hour)	23 (6100)	- -	- -	4900 (1300)	140 (38)	- -

Table 1 (Continued). BASIC VESSEL AND RATE DATA FOR BILGE WATER

Bilge Sample Number	28	29-34	35,36	37	38	39
Vessel Type	Lake Carrier	Lake Carrier	Lake Carrier	Bulk Carrier	Lake Carrier	Lake Carrier
Vessel Nationality	U.S.	U.S.	Yugoslavian	Polish	U.S.	U.S.
Propulsion System	St.Turb.	St.Turb.	Diesel	Diesel	Tr.Expan.Steam	Steam
Vessel Age (yrs.)	20	32	5	4	47	14
Bilge Water Sources	pumps, shaft seal	shaft seal, cooling water, pumps, leaks	misc.	misc.	shaft seal, cooling water	shaft, cooling water
Bilge Pumps, Number	1	2	1	1	1	1
Pumping Frequency	1/30-45min.	continuous	continuous	continuous	1/10-15min.	1/hr.
Bilge Water Pumped, m^3 (gal.)	3.0 (790)	-	-	-	-	-
Duration of Pumping	4-5min.	-	-	-	4-5min.	10min.
Apparent Generation Rate: liters/hour (gallons/hour)	4.7 (1250)	16,000 (4200)	18,000 (4800)	25,000 (6700)	23,000 (6000)	- -

Table 1 (Continued). BASIC VESSEL AND RATE DATA FOR BILGE WATER

Bilge Sample Number	40	41	42	43	44	45	46
Vessel Type	General Cargo	Bulk Carrier	Bulk Carrier	Bulk Carrier	Bulk Carrier	Bulk Carrier	Bulk Carrier
Vessel Nationality	Danish	Greek	U.S.	British	Norwegian	French	Yugoslavian
Propulsion System	Diesel	Diesel	St.Turb.	Diesel	Diesel	Diesel	Diesel
Vessel Age (yrs.)	-	2	62	1	4	2	-
Bilge Water Sources	shaft seal	general leakage	cooling water	general leakage	wash water	general leakage	general leakage
Bilge Pumps, Number	2	2	1	1	2	1	1
Pumping Frequency	-	1/mo.	continuous	1/wk.	1/mo.	1/mo.	as necessary
Bilge Water Pumped, m^3 (gal.)	-	6 (1600)	-	5 (1300)	22 (5900)	17 (4400)	-
Duration of Pumping	-	20 min.	-	15 min.	10 min.	10 min.	-
Apparent Generation Rate: liters/hour (gallons/hour)	15,000 (4000)	8 (2.2)	19 (5)	30 (8)	30 (8)	23 (6)	-

Table 1 (Continued). BASIC VESSEL AND RATE DATA FOR BILGE WATER

Bilge Sample Number	48	49	50	51	52	53
Vessel Type	Bulk Carrier	Tanker	General Cargo	Bulk Cargo	Bulk Carrier	Bulk Carrier
Vessel Nationality	Canadian	Norweigan	Yugoslavian	German	Canadian	Canadian
Propulsion System	Diesel	Diesel	Diesel	Diesel	Diesel	Triple Expansion Steam
Vessel Age (yrs.)	7	18	7	7	8	60
Bilge Water Sources	shaft seal	shaft seal, wash water, condensate, sink wastes	shaft seal, engine	misc.	shaft seal, engines, ballast pumps	cooling water, shaft seal
Bilge Pumps, Number	1	1	1	1	1	1
Pumping Frequency	-	1/day	1/2-3 days	1/day	1/day	-
Bilge Water Pumped, m^3 (gal.)	-	11 (3000)	3.5 (940)	45 (12,000)	20 (5250)	-
Duration of Pumping	-	30 min.	-	25 min.	15-20 min.	-
Apparent Generation Rate: liters/hour (gallons/hour)	8 (2)	470 (125)	60 (16)	1900 (500)	830 (220)	-

Table 1 (Continued). BASIC VESSEL AND RATE DATA FOR BILGE WATER

Bilge Sample Number	54	55	56	57	58
Vessel Type	Bulk Carrier	Bulk Carrier	Bulk Carrier	Bulk Carrier	Bulk Carrier
Vessel Nationality	Canadian	Canadian	Canadian	Canadian	Canadian
Propulsion System	Diesel	St.Turb.	St.Turb.	St.Turb.	St.Turb.
Vessel Age (yrs.)	5	10	16	12	9
Bilge Water Sources	shaft seal, wash water, laundry, drinking water	shaft seal, cooling water, pumps	shaft seal, cooling water, pumps	stern gland, pumps	shaft seal, pumps
Bilge Pumps, Number	2	2	1	1	1
Pumping Frequency	1/2 weeks	1/day	1/2 hr.	1/4 hr.	1/2 to 1 hr.
Bilge Water Pumped, m^3 (gal.)	1.1 (300)	120 (32,000)	3.4 (900)	26 (6800)	20 (5250)
Duration of Pumping	-	90 min.	2-4 min.	20 min.	15-20 min.
Apparent Generation Rate: liters/hour (gallons/hour)	7 (1.8)	5100 (1350)	1700 (450)	6400 (1700)	26,000 (7000)

engineers were willing to provide estimates of bilge water pumped, in others only of pumping duration. The last row in Table 1 indicates the apparent bilge water generation rate as calculated from the more basic data in the 3 rows above; these numbers are essentially the bilge water pumped as averaged over the inverse of the pumping frequency. For instance, for sample 58 the data indicates that 20 cubic meters are pumped every 0.75 hour (the mid-range value); the apparent rate is, therefore, 26 cubic meters per hour.

Table 2 gives the analytical results for the bilge water samples. These sample analyses may be related to the vessel characteristics of Table 1 by referring to the bilge sample numbers. Sampling location refers generally to the area in which samples were taken up (e.g., by a sample bottle or the suction of the sampling pump). Most samples were obtained from propeller shaft alleys, a common bilge area which most always contains standing water and bilge pump. In two cases pump room and engine room samples were taken for the purpose of comparison to shaft alley samples. "General bilge" refers to samples off bilge pumps or oil/water separators. Row 3 of Table 2 refers to sample type or sampling procedure as described in Section V. "Grab" and "recycle" are shorthand terminology for submersion and recirculation sampling respectively; sampling times as measured from starting of the sampling pump are included with the latter. The bilge pump and separator discharge samples are by far the most representative samples possible. Rows 4 to 13 contain the analytical results for the bilge water samples, as described in Section V. Also, some samples were analyzed only for oil. Sample loss (e.g., breakage of bottles) and undue analytical interference (e.g., by large quantities of oil) also are responsible for the lack of certain data points. Note that grab sampling predominates towards the end of the two month study period. An attempt was made to gather more grab samples to balance out the program; however, this attempt almost became permanent when the sample pump broke down and took over 3 weeks to be repaired.

Table 3 presents the results of emission spectroscopy analyses for trace elements on 8 bilge water samples and one sewage sample. This table is self-explanatory. Vessel, generation rate and analytical data for sewage sample number 1 will be presented later.

BALLAST WATER

Table 4 presents basic vessel and discharge data for ballast water samples. The first 3 rows are similar to those for bilge water. Cargo type is given in row 4 because of possible cross-contamination between cargo and ballast water. Row 5 presents total ballast water capacity (in metric tons) as provided by the ships' engineers from design specifications. Trip ballast (row 6) was obtained from the engineers' logs and represents the quantity of ballast water actually loaded at the last port of call; the source water body for this original ballast is listed in row 7. Row 8 gives the total ballast water discharged at the Duluth-Superior Harbor. The ballast tank sampled is identified in row 9 by size and location. Row 10 indicates the amount which the sampled tank's water was diluted enroute to Duluth-Superior, if any. The source of the dilution ballast water is

Table 2. ANALYTICAL RESULTS FOR BILGE WATER

Bilge Sample Number	1	2	3	4	5	6	7	8
Sampling Location	shaft alley	shaft alley	pump room	shaft alley	shaft alley	shaft alley sump	shaft alley sump	shaft alley sump
Sample Type	30 min. recycle	60 min. recycle	30 min. recycle	30 min. recycle	grab	20 min. recycle	40 min. recycle	60 min. recycle
Biological Oxygen Demand (5 day)(mg/l)	64	40	4	80	168	14.5	18.0	19.0
Chemical Oxygen Demand (mg/l)	321	275	54	312	6464	128	116	172
Suspended Solids (mg/l)	33	27	20	288	212	47	49	68
Volatile Suspended Solids (mg/l)	23	18	9	236	181	31	33	45
Settleable Solids (mg/l)	.02	.02	.02	156	157	25	26	39
Phosphorus (mg/l)	.51	.48	.14	1.49	1.54	.07	.06	.08
pH	8.25	8.15	8.12	5.58	7.45	7.35	7.45	7.45
Total Coliform (MPN/100ml)	3.6×10^5	1.7×10^5	4.8×10^4	10	2.88×10^5	1.43×10^5	1.89×10^5	1.02×10^5
Total Organic Carbon (mg/l)	-	-	-	-	-	-	-	-
Oil (mg/l)	137	115	16.6	-	2370	-	-	45.8

Table 2 (Continued). ANALYTICAL RESULTS FOR BILGE WATER

Bilge Sample Number	9	10	11	12	13	14	15	16
Sampling Location	shaft alley	shaft alley	shaft alley	general bilge	general bilge	general bilge	general bilge	shaft alley
Sample Type	30 min. recycle	60 min. recycle	90 min. recycle	bilge pump	separator discharge	bilge pump	separator discharge	grab
Biological Oxygen Demand (5 day)(mg/l)	18	130	52	14	25	18	48	49
Chemical Oxygen Demand (mg/l)	752	1216	1416	632	424	356	84	148
Suspended Solids (mg/l)	196	392	-	30	45	37	24	17
Volatile Suspended Solids (mg/l)	93	387	-	21	44	9	16	16
Settleable Solids (mg/l)	118	288	-	15	23	27	12	12
Phosphorus (mg/l)	2.48	3.47	4.58	.74	.05	.06	.18	.19
pH	7.10	7.10	-	6.75	7.10	7.35	7.00	9.33
Total Coliform (MPN/100ml)	$52x10^3$	$1.4x10^5$	-	$20.2x10^5$ 20,000*	$5x10^4$	4600	$84x10^3$	$10x10^2$
Total Organic Carbon (mg/l)	-	-	160	99	78	21	33	61
Oil (mg/l)	-	-	462	148	88.7	0.4	4.3	35.8

*Fecal Coliform

Table 2 (Continued). ANALYTICAL RESULTS FOR BILGE WATER

Bilge Sample Number	17	18	19	20	21	22	23	24
Sampling Location	shaft alley	shaft alley	engine room	shaft alley	shaft alley	shaft alley	shaft alley	shaft alley
Sample Type	grab	grab	grab	initial recycle	30 min. recycle	60 min. recycle	90 min. recycle	120 min. recycle
Biological Oxygen Demand (5 day)(mg/l)	10	55	7	85	-	-	-	-
Chemical Oxygen Demand (mg/l)	84	68	8	3800	-	-	-	-
Suspended Solids (mg/l)	32	42	8	70	-	-	-	-
Volatile Suspended Solids (mg/l)	21	20	7	50	-	-	-	-
Settleable Solids (mg/l)	9	30	5	13	-	-	-	-
Phosphorus (mg/l)	.13	.21	1.46	.48	-	-	-	-
pH	7.50	7.38	6.92	6.93	-	-	-	-
Total Coliform (MPN/100ml)	7.2×10^5	35×10^3	1.62×10^3	13.2×10^5	-	-	-	-
Total Organic Carbon (mg/l)	-	-	-	-	-	-	-	-
Oil (mg/l)	2.8	16.8	3.3	214	259	215	408	545

Table 2 (Continued). ANALYTICAL RESULTS FOR BILGE WATER

Bilge Sample Number	25	26	27	28	29	30	31	32
Sampling Location	shaft alley	general bilge	shaft alley	general bilge	general bilge	shaft alley	general bilge	general bilge
Sample Type	150 min. recycle	separator discharge	grab	bilge pump	bilge pump	grab	bilge pump	bilge pump
Biological Oxygen Demand (5 day)(mg/l)	80	50	24	75	<1.0	5.0	3.0	not tested at Duluth
Chemical Oxygen Demand (mg/l)	5000	760	56	11,040	40	324	108	-
Suspended Solids (mg/l)	47	75	18	476	32	108	40	-
Volatile Suspended Solids (mg/l)	35	67	15	266	12	91	28	-
Settleable Solids (mg/l)	6	12	14	56	14	96	20	-
Phosphorus (mg/l)	.40	.76	1.00	12.8	.008	.013	.010	-
pH	7.29	7.15	7.58	4.24	8.59	8.32	8.24	-
Total Coliform (MPN/100ml)	5.9×10^5	1.3×10^5	1.1×10^5	0	300	900	400	-
Total Organic Carbon (mg/l)	-	-	-	0	-	-	-	-
Oil (mg/l)	215	155	-	-	-	-	21.5	50.9

Table 2 (Continued). ANALYTICAL RESULTS FOR BILGE WATER

Bilge Sample Number	33	34	35	36	37	38	39	40
Sampling Location	general bilge	general bilge	shaft alley	general bilge	shaft alley	general bilge	general bilge	shaft alley
Sample Type	bilge pump	bilge pump	grab	bilge pump	grab	bilge pump	bilge pump	grab
Biological Oxygen Demand (5 day)(mg/l)	-	4.8	380	410	-	96	88	350
Chemical Oxygen Demand (mg/l)	-	180	3568	3624	-	104	120	1856
Suspended Solids (mg/l)	-	46	3600	1464	-	61	90	1022
Volatile Suspended Solids (mg/l)	-	34	3460	1310	-	53	66	1016
Settleable Solids (mg/l)	-	18	3358	1198	-	40	61	989
Phosphorus (mg/l)	-	.042	0.37	.16	-	.42	2.72	.96
pH	-	8.03	7.73	7.27	-	7.11	7.19	5.13
Total Coliform (MPN/100ml)	-	200	5.7×10^4	5.84×10^5	-	300	200	8×10^4
Total Organic Carbon (mg/l)	-	-	-	-	-	-	-	-
Oil (mg/l)	39.9	29.9	17%	35%	16%	57.6	52.7	2273

Table 2 (Continued). ANALYTICAL RESULTS FOR BILGE WATER

Bilge Sample Number	41	42	43	44	45	46	47	48
Sampling Location	shaft alley	general bilge	shaft alley	shaft alley	shaft alley	shaft alley	general bilge	general bilge
Sample Type	grab	bilge pump	grab	grab	grab	grab	separator discharge	separator discharge
Biological Oxygen Demand (5 day)(mg/l)	>350	>350	>350	1075	-	>3700	7.5	>740
Chemical Oxygen Demand (mg/l)	2208	1424	49880	4496	-	-	88	3168
Suspended Solids (mg/l)	1754	159	-	375	-	-	426	32
Volatile Suspended Solids (mg/l)	1682	123	-	326	-	-	406	20
Settleable Solids (mg/l)	1192	97	-	206	-	-	219	10
Phosphorus (mg/l)	3.73	8.53	1.14	2.80	-	.27	0.075	1.09
pH	7.30	7.75	-	7.32	-	-	9.44	10.24
Total Coliform (MPN/100ml)	2.1×10^7	9.9×10^5	2.5×10^5	4×10^6	-	9.3×10^5	-	< 100
Total Organic Carbon (mg/l)	-	-	-	-	-	-	-	-
Oil (mg/l)	3%	1840	81%	-	202	72%	6.8	847

Table 2 (Continued). ANALYTICAL RESULTS FOR BILGE WATER

Bilge Sample Number	49	50	51	52	53	54	55	56
Sampling Location	shaft alley	shaft alley	shaft alley	shaft alley	general bilge	shaft alley	general bilge	shaft alley
Sample Type	grab	grab	grab	grab	bilge pump	grab	separator discharge	grab
Biological Oxygen Demand (5 day)(mg/l)	>1850	1688	198	1750	1	1100	1	-
Chemical Oxygen Demand (mg/l)	16,800	51,680	1152	40,640	64	22,320	56	192
Suspended Solids (mg/l)	292	5216	210	2280	14	330	16	97
Volatile Suspended Solids (mg/l)	262	5008	196	2010	9	286	6	71
Settleable Solids (mg/l)	146	4912	110	2240	5	251	14	74
Phosphorus (mg/l)	.93	.82	.86	8.80	.13	.064	.040	.21
pH	8.68	8.36	7.69	9.43	7.89	9.96	10.34	7.69
Total Coliform (MPN/100ml)	3.52×10^6	2.29×10^6	1.9×10^5	4×10^6	3.52×10^4	4.3×10^6	9×10^2	4.3×10^6
Total Organic Carbon (mg/l)	-	-	-	-	-	-	-	-
Oil (mg/l)	25%	21%	339	63%	11.4	4%	19.2	76.2

Table 2 (Continued). ANALYTICAL RESULTS FOR BILGE WATER

Bilge Sample Number	57	58	
Sampling Location	general bilge	shaft alley	
Sample Type	bilge pump	30 min. recycle	
Biological Oxygen Demand (5 day)(mg/l)	-	10	
Chemical Oxygen Demand (mg/l)	76	496	
Suspended Solids (mg/l)	14	2299	
Volatile Suspended Solids (mg/l)	10	149	
Settleable Solids (mg/l)	9	188	
Phosphorus (mg/l)	.033	3.33	
pH	9.44	8.42	
Total Coliform (MPN/100ml)	1.36×10^3	1.2×10^4	
Total Organic Carbon (mg/l)	-	-	
Oil (mg/l)	18.6	143	

Table 3. TRACE ELEMENTS IN BILGE AND SEWAGE SAMPLES BY EMISSION SPECTROSCOPY

(mg/l)

Sample Type :	Sewage	Bilge	Bilge	Bilge	Bilge	Bilge	Bilge	Bilge	Bilge
Sample Number:	1	1	2	3	11	12	13	14	15
Element									
Ag	<.08	<.03	<.03	<.03	<0.04	<0.03	<0.03	<0.02	<0.04
Al	1.3	1.2	.8	2.1	6.8	1.9	0.08	0.98	0.05
As	<.8	<.3	<.3	<.3	<0.4	<0.3	<0.3	<0.2	<0.3
B	<.3	1.0	<.08	<1.9	<0.1	<0.1	<0.1	<0.06	<0.1
Ba	<.3	<.1	<.08	<.09	<0.1	<0.1	<0.1	<0.06	<0.1
Be	<.08	<.03	<.03	<.03	<0.04	<0.03	<0.03	<0.02	<0.04
Cd	<.3	<.1	<.08	<.09	<0.1	<0.1	<0.1	<0.06	<0.1
Co	<.3	<.03	<.03	<.03	<0.04	<0.03	<0.03	<0.02	<0.04
Cr	<.08	<.03	<.03	<.03	0.2	0.07	<0.03	0.04	<0.04
Cu	1.8	.2	.2	.4	1.5	0.95	0.27	0.14	0.07
Fe	3.3	2.4	2.4	3.3	47.5	14.0	2.7	2.6	5.2
Mn	.08	.06	.06	.09	0.30	0.20	0.08	0.17	0.33
Mo	<.08	<.03	<.03	<.03	<0.04	<0.03	<0.03	<0.02	<0.04
Ni	<.08	<.03	<.03	<.03	0.2	0.8	<0.03	<0.02	0.2
P	<3.	<3.	<3.	<3.	<4.	<3.	<3.	<2.	<4.
Pb	<.08	<.03	<.03	<.03	2.7	0.51	<0.1	<0.06	0.10
Sb	<.8	<.3	<.3	<.3	<0.1	<0.1	<0.1	<0.06	<0.1
Sn	<.08	<.03	<.03	<.03	<0.04	<0.03	<0.03	<0.02	<0.04
Sr	<.3	<.1	<.08	<.09	<0.1	<0.1	<0.1	<0.06	<0.1
Ti	<.08	<.03	<.03	<.03	0.60	0.12	<0.03	0.08	<0.04
V	<.08	.14	.15	<.03	<0.04	0.2	<0.03	<0.02	<0.04
Zn	<.8	<.3	<.3	<.3	3.5	1.0	1.0	<0.2	0.9
Zr	<.08	<.03	<.03	<.03	<0.04	<0.03	<0.03	<0.02	<0.04
Ca	13.9	16.4	18.0	15.9	11.5	15.5	21.9	14.0	17.6
Mg	10.4	9.6	9.0	8.5	8.8	8.9	10.9	7.9	8.5
Na	46.3	21.7	16.1	8.7	8.8	11.5	23.2	6.0	17.6
Si	12.7	17.6	5.5	22.1	23.7	10.4	3.5	6.6	1.6

Table 4. BASIC VESSEL AND DISCHARGE DATA FOR BALLAST WATER

Ballast Sample Number	1-3	4	5 & 6	7	8	9-12	13
Vessel Type	Lake Carrier	Bulk Carrier	Lake Carrier	Lake Carrier	Bulk Carrier	Lake Carrier	Lake Carrier
Vessel Nationality	U.S.	Liberian	Canadian	Canadian	British	U.S.	Canadian
Cargo Type	ore	general & Grain	grain	grain	steel & Grain	ore	grain
Total Ballast, M.T.	15,300	-	15,200	11,400	7,300	13,700	11,400
Trip Ballast, M.T.	15,300	-	8,200	11,400	7,300	12,300	11,400
Original Ballast Source	Detroit	Detroit	Buffalo	Lake Erie	Detroit	Ashtabula	Cleveland
Total Ballast Discharged, M.T.	15,300	248	8,200	10,900	4,160	12,300	10,550
Sampled Ballast Tank, size, M.T., location	1,280 #4 starboard	248 port-side top wing	3,050 #2 port	120 aft peak	301 #3 starboard, top wing	2,080 #6 starboard	910 #2 port
Sampled Tank Dilution Enroute, M.T.	750	0	0	0	0	0	0
Source of Dilution Ballast	Lakes Huron & Superior	n/a	n/a	n/a	n/a	Lake Superior	n/a

given in row 11; note that for the sixth vessel, ballast water dilution occured although not for the sampled tank.

The analytical results for ballast water are presented in Table 5. These may be related to the vessel data of Table 4 by the sample numbers. All the samples were of the "grab" type with a Kemmerer Sampler supplied by the Western Lake Superior Sanitary District. Sample type (row 2) is, therefore, differentiated only on the basis of whether a single or composite grab sample was obtained. Single grab samples were taken initially a different depths to determine if water quality varied drastically with depth. Composite samples were taken thereafter to reduce the analytical burden. Row 3 gives the sampling and total water depth for the ballast tank of interest; for sample 1, for instance, the sample was taken at 1.5 meters (5 feet) from the tank bottom with a total water depth of 3.0 meters (10 feet). Row 4 through 13 present the wastewater analytical data as described in Section V. Again, the Edison Water Quality Laboratory was requested to run oil and TOC analyses on only a selected few samples. Samples 9 through 12 were from a trip from Ashtabula, Ohio to Duluth. Samples 9 and 12 are for harbor waters as is noted on the table; the ballast water of samples 10 and 11 was obtained from the Ashtabula Harbor (sample 9) and discharged to the Duluth Harbor (sample 12).

SEWAGE

Table 6 presents the basic vessel and rate data collected during the study for sewage. This table is self-explanatory. Row 6, sewage system size, refers basically to holding capacity and, therefore, does not apply to the flow through system of the fifth vessel. Combined wastes (row 7) refer to toilet, urinal, lavatory, shower, galley, shop and laundry wastewaters; sanitary wastes are only the first two of these. Deodorizers and disinfectants used are indicated in row 8. Recirculation or mixing capability (row 9) refers to whether sewage could be stirred, manually or otherwise, in a tank. Pumpout frequency (row 10) and volume (row 11) were given to the field crew by either the vessel captain or engineer. Apparent generations rates (row 12) were calculated using median values for crew size, pumpout frequency and pumpout volume. Since the flow through system was not instrumented, a generation rate estimate was not possible.

Table 7 gives the analytical results for the sewage samples. The second row indicates how the samples were taken: from wastewater effluent line or pump or directly from the holding tank. The remainder of the table is laboratory data; oil was analyzed for only a select 3 samples.

GARBAGE/REFUSE

Garbage generation by foreign vessels at Duluth-Superior Harbor during the Fall of 1973 is summarized in Table 8; the 20 vessels listed represent approximately 25% of those which were serviced by Bayfront Marine Services, Inc. during the 2-1/2 month field study period. Column 1 identifies

Table 5. ANALYTICAL RESULTS FOR BALLAST WATER

Sample Number	1	2	3	4	5	6	7	8	9[1]	10	11	12[2]	13
Sample Type	grab	grab	grab	grab	grab	grab	composite	composite	composite	composite	composite	composite	grab
Sample and Water Depth, m./m., (ft./ft.)	1.5/3.0 (5/10)	3.0/3.0 (10/10)	0.3/3.0 (1/10)	1.2/2.4 (4/8)	0/3.7 (0/12)	1.8/3.7 (6/12)	0,0.9,1.8/1.8 (0,3,6/6)	0,1.8,3.7/3.7 (0,6,12/12)	0.3,1.8,3.7/n.a (1,6,12/n.a)	0.3,3.7,7.3/7.6 (1,12,24/25)	0.3,3.7,7.3/7.6 (1,12,24/25)	0.3,1.8,3.7/n.a (1,6,12/na)	1.5/7.6 (5/26)
Biological Oxygen Demand (5 day), mg/l	0.4	0.6	2.0	2.5	0.8	0.6	8.4	5.5	2.0	2.0	2.8	1.8	1.0
Chemical Oxygen Demand, mg/l	12	8	16	58	36	32	12	140	4	12	40	4	16
Suspended Solids, mg/l	2.0	2.4	2.8	7.6	9	10	11	126	17	15	7	4	13
Volatile Suspended Solids, mg/l	1.6	1.6	2.0	4.4	5	6	7	57	6	4	7	4	11
Settleable Solids, mg/l	Tr.	Tr.	Tr.	2.8	4	4	10	109	15	10	3	4	9
Phosphorous, mg/l	0.03	0.013	0.017	0.03	0.01	0.01	0.05	0.39	0.022	0.025	0.17	0.015	0.087
pH	7.56	7.65	7.70	6.40	7.05	7.15	7.38	6.50	7.32	7.71	8.01	8.03	8.40
Oil, mg/l	-	-	-	2.7	0.0	0.0	2.4	43	-	-	-	-	0.7
Total Coliform, MPN/100 ml	8.1×10^3	2.7×10^3	1.5×10^3	2.1×10^4	4.3×10^3	5.5×10^3	3×10^2	1.5×10^5	8×10^2	5.6×10^2	6.6×10^2	5.2×10^2	1.0×10^5
Total Organic Carbon, mg/l	-	-	-	-	5	5	22	27	-	-	-	-	-

*Emission spectroscopy data presented separately. (1) Ashtabula Harbor water. (2) Duluth Harbor water

Table 6. BASIC VESSEL AND RATE DATA FOR SEWAGE

Sample Number	1	2	3	4	5	6
Vessel Type	Cutter	Bulk Carrier	Lake Carrier	Lake Carrier	Lake Carrier	Lake Carrier
Vessel Nationality	U. S.	Liberian	U. S.	U. S.	U. S.	Canadian
Crew Size	45	25-27	38	32	32	32
Sewage System Type	holding	septic tank	holding	holding (3)	Flow through (Biological)	holding
Sewage System Size, liters (gallons)	18,900 (5000)	5,700 (1500)	80,200 (21,200)	6,800 (1,800)	-	15,100 (4000)
Waste Type	combined	combined	combined	sanitary	combined	sanitary
Chemicals Used	beozene & DO5725 (1)	none	NaOCl	MC 1000 (2)	$Ca(OCl)_2$	$Ca(OCl)_2$
Recirculation Capability	none	none	hand stirrer	hand stirrer	-	none
Pumpout Frequency Reported (days)	1/2-1/3	-	5-7	10	-	4
Pumpout Volume Reported, liters (gallons)	3800-11,400 (1000-3000)	-	75,700 (20,000)	5100-5500 (1350-1450	-	15,100 (4000)
Apparent Generation Rate, liters/day/man (gal./day/man)	415 (110)	-	340 (90)	17 (4.5)	n/a	115 (30)

(1) Brulin Co.
(2) Monogram Industries
(3) Flush water reused until sent to holding tank (every 4 or 5 days).

Table 7. ANALYTICAL RESULTS FOR SEWAGE

Sample Number	1*	2	3	4	5	6
Sample Type	from 1" effluent line	bled from pump	grab from tank w/ stirring	bled from tank w/ stirring	from 1" effluent line	from 4" effluent line
Biological Oxygen Demand (5 day) (mg/l)	250	900	1700	820	68	-
Chemical Oxygen Demand (mg/l)	708	2000	6856	44,400	344	1112
Suspended Solids (mg/l)	260	644	8520	692	185	628
Volatile Suspended Solids (mg/l)	226	476	8272	524	162	520
Settleable Solids (mg/l)	106	208	8168	484	163	452
Phosphorus, mg/l	13.6	20.8	18.6	67.3	6.4	9.9
pH	7.07	7.00	6.70	8.52	8.39	8.12
Oil (mg/l)	220	3.1	-	-	-	57.3

* Emission spectroscopy data presented separately

Table 8. SHIPBOARD GARBAGE GENERATION

Vessel Nationality	Garbage Weight, Net (kg)	Days for Generation	Crew Size (no.)	Generation Man-days	Generation Rate (kg/man-day)
Cypriot	635	7	38	266	2.4
Yugoslavian	435	10	36	360	1.2
Spanish	270	3	27	81	3.8
Greek	435	8	29	232	1.9
Greek	710	10	32	320	2.2
Greek	890	6	39	234	3.8
British	425	3	38	114	3.8
Panamanian	1,080	6	27	162	6.7
Belgian	1,805	11	30	330	5.4
British	1,480	8	37	296	5.0
Norwegian	845	4	30	120	7.0
Panamanian	735	5	31	155	4.8
British	590	5	32	160	3.8
Greek	660	9	26	234	2.8
Norwegian	770	5	28	140	5.5
Norwegian	955	6	38	228	4.2
Yugoslavian	425	7	34	238	1.8
Yugoslavian	915	7	34	238	3.8
French	170	2	32	64	2.7
Greek	180	2	33	64	2.8
Total	14,400			4,036	

Average Generation Rate: 3.6 kg/man-day (7.9 lbs./man-day)

vessels by nationality. Note that only foreign garbage/refuse is considered because of agricultural regulations relating to possible infestation and requiring disposal within 24 hours. Only foreign vessel garbage/refuse is collected at a central location in the harbor and amenable to sampling; therefore, U. S. and Canadian vessels could not be considered in this study. The weight of garbage from each vessel (column 2) was determined by weighing the collection truck on a truck scale at a local scrap yard. The days for garbage/refuse generation and crew size (columns 3 and 4, respectively) were determined through interview of vessel captains or other knowledgeable officers. Days for generation multiplied by crew size gives generation man-days (column 5); this latter quantity divided into the net garbage weight gives the generation rate (column 6). The totals (for all the vessels) were used similarly to come up with the overall average generation rate listed at the bottom of Table 8.

Table 9 gives garbage sample analyses. Samples 1 and 2 were from the Belgian and 3 and 4 from the third Yugoslavian vessel listed on Table 8. The top portion of Table 9 contains the waste category compositions for the samples as determined by hand sorting (see Section V). Note that samples 1 and 4 contained exceptionally large amounts of textiles and metals respectively; the former appeared to be waste shop rags, the latter waste iron scale. The weight percent water and the dry and wet heat values at the bottom of the table were determined by the Twin Cities Testing Laboratory. Since these basic values apply only to the total of food, paper and wood wastes, the total heat value for the garbage/refuse had to be estimated. Data from Principles and Practices of Incineration (p. 7) by Richard C. Corey was used to adjust the laboratory data; the estimated total heat values so obtained are for wet garbage/refuse.

DUNNAGE

Only two vessel loads of dunnage were available during the last 2 months of the field study; due to the attention required of the other waste categories, dunnage was not considered during the first two weeks. A bulk carrier (Greek) carrying steel unloaded 7.7 metric tons (16,920 pounds) of dunnage in early September 1973. In mid-September another bulk carrier unloaded approximately 9.1 metric tons (20,000 pounds) although the field crew, due to complaints by longshoremen, could only weigh half (5) the truckloads. This, unexpectedly, proved to be the last dunnage available during the course of the project.

Table 10 presents a size distribution analysis for the first load of dunnage weighed. The distribution was determined as described in Section V. This load of dunnage contained about a pound or 450 grams of scrap metal, mainly in the form of nails, and was comprised entirely of pine lumber. Table 10 shows uncoupled distributions for length, width, and thickness.

Table 9. GARBAGE SAMPLE ANALYSES

Sample Number	1	2	3	4
Component	% by Weight			
Food Wastes	53.4	71.3	62.8	59.4
Paper Products	5.5	8.6	11.4	8.2
Plastic, Rubber, Leather	2.0	6.0	1.1	0.5
Textiles	23.2	1.7	4.5	1.5
Wood	0.4	0.0	0.0	0.0
Metals	2.1	3.9	1.7	21.7*
Glass, Ceramics	13.4	8.5	18.5	8.7
Total	100.0	100.0	100.0	100.0

*Includes 20 percentage points due to waste iron scale.

Weight % H_2O**	32.2	31.8	51.4	40.0
Dry Heat Value, cal/g, (BTU/lb)**	5120 (9210)	5300 (9540)	4010 (7220)	3130 (5640)
Wet Heat Value, cal/g, (BTU/lb)**	3470 (6240)	3620 (6510)	1950 (3510)	1880 (3380)
Estimated Total Heat Value, cal/g, (BTU/lb)***	3080 (5550)	3350 (6030)	1690 (3050)	1380 (2480)

** Applies to total of food, paper and wood wastes only.
*** Lab value corrected to account for the other four waste components by using published data.

Table 10. DUNNAGE SIZE DISTRIBUTIONS

Length

Range(m)	No. Percent
0-0.3	0.0
0.3-0.61	0.0
0.61-0.91	1.6
0.91-1.22	5.4
1.22-1.52	6.0
1.52-1.83	16.3
1.83-2.13	14.7
2.13-2.44	9.8
2.44-2.74	26.7
2.74-3.05	5.4
3.05-3.35	11.4
3.35-3.66	2.2
3.66-3.96	0.5
>3.96	0.0
	100.0

Average Length: 2.2 m.

Width

Range(cm)	No. Percent
0- 5.1	0.0
5.1-10.1	15.9
10.1-15.2	35.4
15.2-20.3	20.7
20.3-25.4	12.5
25.4-30.4	6.0
30.4-35.5	4.8
35.5-40.6	2.1
40.6-45.6	1.0
45.6-50.7	0.0
50.7-55.8	1.1
55.8-60.9	0.5
>60.9	0.0
	100.0

Average Width: 16.6 cm.

Thickness

Size(cm)	No. Percent
<2.5	0.0
2.5	88.0
3.8	6.0
5.1	0.5
6.3	0.5
7.6	4.9
>7.6	0.0
	100.0

Average Thickness: 2.9 cm.

SECTION VII

ANALYSIS OF RESULTS

Except for bilge water, the results of this study can be analyzed and summarized directly from the data of Section VI. The analyses which follow serve to highlight the major results and conclusions of the study. More extensive field work could, of course, lead to much more data and statistically exact analyses of same, including estimates of pure error. For the purposes of this study, analysis aims primarily at quantifying environmental and pollution problems for the five waste categories.

BILGE WATER

Only 26 of the 37 vessels sampled for bilge water were able to supply useful data for estimating generation rates. Table 11 summarizes the bilge water generation rate data. The number of vessels in a particular category is given along with apparent generation rate and standard deviation for same. The standard deviations are not estimates of pure error, although the latter contributes to them; rather, the deviations reflect real differences in bilge water generation from vessel to vessel. These variations are large and very significant. Of course, more exact insight into vessel-to-vessel variations can be gained by detailed study of the data in the previous section.

The average vessel studied generated 6,650 liters or 1,760 gallons of bilge water per hour. This is generally in line with the values used (not estimated through extensive survey) in other studies. For instance, Environmental Quality Systems, Inc., in a study for the Upper Great Lakes Regional Commission used a typical generation rate of 12,000 liters per hour; Frederic R. Harris, Inc. used a value of 600 liters per hour for pre-1953 steam driven Lake carriers. Steam driven vessels apparently generate bilge water at about 2-1/2 times the rate of diesels. This can be explained by the formers' relatively greater ages and sizes plus leakier propeller shaft seals. This result, of course, applies to vessels at Duluth-Superior, or, perhaps more generally, to vessels plying the Great Lakes. The ages, vessel sizes and predominant steam propulsion of the United States fleet on the Lakes is reflected in the generation rates for U. S., Canadian and other foreign vessels: about 10,000, 5,700 and 5,100 liters per hour respectively. Similarly, the data indicates that vessels 20 or more years old generate bilge water at about twice the rate of younger vessels.

The last 3 rows of Table 11 give rates for 3 categories of bilge water generators: low, medium and high, defined by requiring equal numbers of vessels in each group. A 3 orders of magnitude spread in bilge water generation is apparent. These categories were developed mainly to provide

Table 11. APPARENT BILGE WATER GENERATION RATES

Vessel Category	Number	Apparent Generation Rate liters/hr.	(gal./hr.)	Standard Deviation liters/hr.
All	26	6,650	(1,760)	9,090
Steamers	11	10,600	(2,790)	9,920
Diesels	15	4,110	(1,090)	8,130
United States	7	10,300	(2,720)	10,200
Canadian	7	5,720	(1,510)	9,290
Foreign	12	5,060	(1,340)	8,890
New (0 to 5 years)	8	5,400	(1,430)	10,100
Middle Aged (6 to 19 years)	9	4,720	(1,250)	8,290
Old (20 years or more)	7	10,300	(2,720)	10,200
Low Bilge Water Generator (0 to 30 gph)	9	32.6	(8.6)	32.8
Medium Bilge Water Generator (30 to 1500 gph)	9	2,240	(590)	2,080
High Bilge Water Generator (greater than 1500 gph)	8	19,100	(5,000)	6.570

a basis for comparing waste oil charged to the bilges of vessels generating different amounts of bilge water.

Table 12 summarizes the bilge water data on oil and COD. The same comments about standard deviations hold for this table as for Table 11. Similar tabulations could be made for other important wastewater parameters (e.g., BOD_5 and suspended solids) but the general conclusions would be about the same. The average BOD_5 for the recycle and bilge pump samples collected was 70 mg/l and suspended solids 250 mg/l.

Rows 1 and 2 of Table 12 indicate a large discrepancy between recirculation and grab sampling while rows 3 and 4 show differences between the samples taken by the field engineer and field technician. Even grab samples which the field engineer thought were acceptable (row 5) had markedly higher oil contents than the recycle samples. The conclusion is that grab sampling is unacceptable for bilge water. The general bilge samples split from bilge pump effluent streams were the most representative taken during the study; the oil and COD values for these samples compare very well with those for the shaft alley recycle samples on an average basis. Recirculation, then, in the absence of samples taken from an operating bilge pump seems to be a good technique for obtaining bilge water samples. It, of course, requires taking more than sample bottles onboard vessels (e.g., pump and hose) and a suitable power source. Values from previous studies are 200 mg/l oil used by Environmental Quality Systems, Inc. and 17 to 154 mg/l oil measured by Frederic R. Harris, Inc. When compared to the bilge pump samples, the oil and COD analyses for samples taken from oil/water separator effluents indicate little in the way of beneficial performance.

Although the overall results by vessel nationality (rows 14, 15 and 16) are biased by the inclusion of grab sample analyses, the general trend fits the impresssions formed by the field crew. That is, U. S. vessels "appeared" cleaner than Canadian vessels which, in turn, appeared cleaner than other foreign vessels; the visual differences, however, were not so dramatic as implied by the analyses. Cleaner operations, more dilution water (e.g., from seal leaks) and use of less diesel power for U. S. and Canadian vessels all serve to explain the analytical differences. The overall results for diesel vessels in the second from the bottom row are obviously biased by the inclusion of 14 grab sample analyses while the similar result for steamers is biased only slightly (i.e., without the 5 grab samples oil would be about 170 milligrams/liter); the results for recycle and discharge sampling of diesels indicate substantially lower oil and COD values. The large relative values for oil and COD resulting from grab (submersion) sampling of diesels are illustrated by row 2 on the second page of Table 12. On the other hand, grab sampling of steamers produced relatively low oil and COD concentrations; this occured for apparently the same reasons as discussed for U. S. vessels above (e.g., dilution effects). Note that grab sampling appears in general to be a very biased technique.

Lines 22, 23 and 24 of Table 12 give results for new, middle-aged and

Table 12. STATISTICAL SUMMARY OF BILGE WATER DATA FOR OIL AND C.O.D.

Category	No.	Mean Oil (mg/l)	SD Oil (mg/l)	No.	Mean COD (mg/l)	SD COD (mg/l)
Shaft Alley/Recycle Samples	11	251	177	12	1,167	1,588
Shaft Alley/Grab Samples	17	178,000	273,000	17	11,900	18,160
Shaft Alley/Grab Samples by Field Engineer	12	122,000	186,000	13	7,460	17,660
Shaft Alley/Grab Samples by Field Technician	5	312,000	414,000	4	14,600	23,500
Shaft Alley/Grab Samples Preferred by Field Engineer	7	41,500	93,100	9	4,570	8,620
General Bilge Samples Off Bilge Pumps	11	206	543	11	1,285	3,250
General Bilge Samples Off Separators	6	187	329	6	1,430	2,030
Recycle & Bilge Pump Samples:						
United States	12	246	517	14	1,285	2,850
Canadian	4	55	61	6	175	162
Foreign Flag	6	309	138	3	3,040	2,435
Grab Samples:						
United States	2	10	10	4	114	142
Canadian	4	168,000	309,000	4	15,800	19,600
Foreign Flag	12	196,000	282,000	10	13,800	20,000
United States Vessels	15	199	468	19	973	2,480
Canadian Vessels	13	51,600	174,000	15	4,540	11,500
Foreign Vessels	20	135,400	240,000	15	10,400	16,900
Diesel-Driven Vessels	24	140,800	245,000	19	11,700	16,900
Steam-Driven Vessels	24	140	375	30	670	2,000

Table 12 (continued)

Category	No.	Mean Oil (mg/l)	SD Oil (mg/l)	No.	Mean COD (mg/l)	SD COD (mg/l)
Diesels by Recycle or Discharge Sampling	10	295	246	7	2,510	2,180
Diesels by Grab Sampling	14	241,000	283,000	12	17,100	19,500
Steamers by Grab Sampling	5	27	31	7	126	106
*New Vessels	18	86,800	202,000	14	7,190	13,500
*Middle-Aged Vessels	14	78,000	179,000	16	7,220	15,900
*Old Vessels	13	206	506	17	1,050	2,620
**Low Bilge Water Generator	8	137,000	281,000	8	17,700	21,500
**Medium Bilge Water Generator	15	58,900	229,000	14	6,210	11,040
**High Bilge Water Generator	12	56,900	112,000	11	976	1,390
For Recycle or Discharge Samples:						
**Low Bilge Water Generator (44 gms/hr. oil waste)	2	1,343	702	2	2,300	1,230
**Medium Bilge Water Generator (620 gms/hr oil waste)	9	277	165	8	3,500	3,580
**High Bilge Water Generator (860 gms/hr oil waste)	8	45	44	8	170	158

* New Vessels: 0 to 5 years
Middle-Aged Vessels: 6 to 19 years
Old Vessels: 20 years and over

** Low Bilge Water Generator: 0 to 30 gph
Medium Bilge Water Generator: 30 to 1500 gph
High Bilge Water Generator: greater than 1500 gph

old vessels; although biased by grab samples, this data shows that older vessels discharge bilge water with lower oil concentrations due primarily to dilution. The remaining 6 rows of Table 12 generally illustrate the same fact, even when grab samples are included for low, medium and high bilge water generators (rows 25, 26 and 27). When only recycle and discharge sampling is considered for these 3 degrees of bilge water generation, dilution effects are even more apparent. In fact, the relative constancy of the apparent waste oil discharged with the bilge water is quite surprising (see the parenthetical expressions in the last 3 lines of Table 12); the average oil discharge rate is about 660 grams/hour for the 19 samples considered.

In conclusion, bilge water appears to be a serious pollution problem at the Duluth-Superior Harbor and on the Great Lakes. Improvement in oil/water separator technology would seem to be in order. Bilge water generation rates are significantly larger, even for new and diesel powered vessels, than often reported in the literature (e.g., "Port Collection and Separation Facilities for Oily Wastes, Volume I" by Frederic R. Harris, Inc.); however, the rates are lower than estimated by the authors of this report in "Duluth-Superior Harbor Pollution Control Program" prepared for the Upper Great Lakes Regional Commission (29 versus 53 gallons/minute). The study has shown that bilge water contains 200 to 250 milligrams/liter of oil and substantial quantities of other common wastewater contaminants. Relative to bilge water generation rates and oil concentrations, the waste oil discharge with bilge water is relatively consistent at 660 grams/hour on the average.

BALLAST WATER

Conclusions regarding non-oily ballast water can be made directly by inspection of Tables 4 and 5 in Section VI. First, deballasting accounts for a considerable discharge of water to the Harbor: 13,800, 6,800 and 8,800 metric tons per visit for ore, bulk grain and all vessels, respectively. These quantities represent 95, 65 and 75 percent of total ballasting capacity, respectively; the overall value is somewhat higher than previously estimated in the report "Duluth-Superior Harbor Pollution Control Program" (67 percent). At present, ballast dilution is, for all practical purposes, negligible at one percent. The analytical results for sample number 12 in Table 5 give an idea as to the existing quality of the water in the Duluth-Superior Harbor. With one exception, the ballast water analyses indicate only from 1/2 to 10 times the magnitudes of the various wastewater parameters for the harbor water. The exception is the single British ship (sample 8) which was carrying quite highly contaminated ballast water; 43 milligrams per liter of apparent oil and grease in a supposedly non-oily wastewater is somewhat disconcerting.

Given the analyses of Table 5, a good rule of thumb appears to be that non-oily ballast water has 2 to 5 times the contaminants as harbor water (not including the results for sample 8). Sample series 9 to 12 indicates that Ashtabula Harbor water is slightly more contaminated than that at Duluth; also, ballast water changed enroute to Duluth: solids

decreased and COD and phosphorous increased due, apparently, to the addition of chemicals and contaminants. Of course, much more severely contaminated water at ballasting points (e.g., upriver at Cleveland) would present more of a problem (e.g., the British ship); however, the project did not allow for extensive harbor water sampling.

In conclusion, as compared to other pollution control and environmental problems at Duluth-Superior, non-oily ballast water does not appear to be a very important wastewater.

SEWAGE

Tables 6 and 7 in Section V gave the basic vessel, rate and analytical data for sewage; again, conclusions are apparent directly from the data. There is considerable variation in type and capacity for sewage systems onboard vessels. Chemical addition is usual practice and, especially for holding systems, could present a real hazard to shoreside wastewater treatment facilities which accept vessel sewage. This is reflected in the number of very high COD analyses in Table 7. Sewage generation rates are in line with accepted values. For this study, combined wastewaters are apparently generated at about 380 liters or 100 gallons per man per day, and sanitary wastewaters at 95 liters or 25 gallons per man per day (accounting for the recycle onboard vessel 4). Municipal wastewaters typically have about 200 milligrams per liter of both BOD_5 and suspended solids. The average values for these two parameters in this study are 750 and 1,600, respectively. This indicates something close to an order of magnitude greater contamination. Vessel sewage is, however, probably overly dosed with bactericides which could also severely impact wastewater treatment facilities.

In conclusion, sewage generation onboard vessels occurs at rates similar to those presented in the literature and used in design. These wastes are, however, highly contaminated compared to municipal wastewaters and include large amounts of chemicals and even oil.

GARBAGE/REFUSE

Data on garbage generation and analyses was presented in Section VI, Tables 8 and 9. Significant variation was observed in generation rates from vessel-to-vessel (about a 2-to-1 peak-to-average ratio) with an average of 3.6 kilograms or 8 pounds of garbage/refuse per man-day. This is high compared to the typical municipal rate of 5.5 pounds per man-day used by the Bureau of Solid Waste Management. No particular dependence on vessel nationality can be discerned from the data. Using Principles and Practices of Incineration as a reference, food wastes comprise a much higher percentage of the total for vessels than for municipal garbage/refuse (62 versus 12 percent); paper wastes are, on the other hand, much less prevalent (8.4 versus 42 percent) while twice as much glass is found (12 versus 6 percent). A problem peculiar to vessels is the inclusion of highly variable quantities of industrial-type wastes; sample analyses 1 and 4 reflect large amounts of shop rags and iron scale from

hull cleaning respectively.

In terms of incineration of vessel garbage/refuse, two problems arise: (1) high moisture content and (2) low heat value. The samples collected at Duluth-Superior Harbor contained an average of 39 percent water which is about twice the value for municipal garbage/refuse. This much water will not only decrease combustibility, but will also cause problems with garbage/refuse transport and handling. The average total heat value for the four samples was 4,300 Btu per pound which compares unfavorably to 6,200 Btu per pound for typical municipal solid wastes.

In conclusion, garbage/refuse is generated at higher rates onboard foreign vessels than municipally and contains large amounts of water which account, primarily, for low total heat values.

DUNNAGE

Not much more than has already been said can be said about dunnage due to lack of the basic waste material during the study period. Data is much too sketchy to allow any sort of an estimate of generation rates. The single size distribution analysis which was made indicates that previous observations of wide size variations hold true. Metal content measurements were also too limited to permit any generalizations although, once again, observations appear correct that the form and amounts of this waste are highly variable.

GENERAL

The data gathered during the study indicates that high variability is the only uniform characteristic of vessel wastes. Although average results can be very useful for describing waste problems on a harbor-wide basis, they cannot be so used for individual vessels. From vessel-to-vessel, both waste quality and quantity can vary by orders of magnitude. The study has shown this most dramatically for bilge water, but it also holds for the other four waste categories. Control or treatment systems for a particular vessel or small number of vessels must be designed using data highly specific to same. Such data is not provided by a study such as that which has just been discussed; rather, special studies will be required.

SECTION VIII

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SECTION IX

APPENDIX

WASTEWATER ANALYSES DESCRIPTIONS

The following pages describe briefly the particular wastewater analyses which were used during the vessel waste study at Duluth-Superior.

BOD_5, COD, suspended solids, volatile suspended solids, settleable solids, phosphorous, pH and total coliform bacteria were determined at the WLSSD's Duluth Sewage Treatment Plant Laboratory. Sample transport from the port to the laboratory took only about 10 minutes, and sample refrigeration was possible at both the Port Authority Terminal and the laboratory. Therefore, little sample degradation could take place. Descriptions of the 8 tests mentioned above are as follows:

(1) BOD_5

Five day BOD tests were performed according to the procedures set forth in "Standard Methods", Section 219. BOD is an empirical test used for determining the relative oxygen requirements of wastewater. Oxygen demand in this particular test is usually attributed to carbonaceous matter. BOD measurements somewhat attempt to simulate natural oxidation. Typical precision is $\pm$ 5%.

(2) COD

COD is a measure of the amount of organic matter oxidized by a strong chemical oxidant. It is especially valuable in industrial waste studies. COD was determined according to "Standard Methods", Section 220. The precision of COD tests is about 6.5% at 200 mg/l. Usually COD reflects 95 to 100% of the theoretical value for oxidizable matter. Organic compounds such as benzene and acetic acid are not oxidized by this dichromate method, however.

(3) SUSPENDED SOLIDS

Suspended solids were determined according to "Standard Methods", Section 224C. Solids are isolated for drying and weighing by filtration with a Gelman filter. Precision depends upon the amount of suspended matter in the sample; at 242 mg/l, $\pm$ 10% variation is typical. Total suspended matter is a gross indicator of pollution in wastewaters.

(4) VOLATILE SUSPENDED SOLIDS

Volatile suspended solids are determined in a continuation of the

procedure for suspended solids ("Standard Methods", Section 224D). Filtered residue is ignited for 15 minutes at 550°C. At 170 mg/l, coefficients of variation are about 6.5%. Volatile suspended solids are usually used as an indicator of the amount of organic solids contained in a wastewater sample.

(5) SETTLEABLE SOLIDS

For the majority of samples, concentrations were determined on a weight basis (mg/l). The procedure used is stated in "Standard Methods", Section 224F. The portion of the wastewater that either settles or floats is determined by difference (suspended less nonsettleable matter). Settleable solids represent, more than anything else, an operational parameter relating to possible separation in settling basins, thickeners, etc.

(6) PHOSPHORUS

The phosphorus level in wastewater was determined by the stannous chloride technique as described in "Standard Methods", Section 223E. This colorimetric method is most suited to concentration of 0.01-6 mg/l. Relative error is usually between 4 and 5%. Phosphorus is, of course, a key element (often limiting) for biological growth in water bodies.

(7) pH

A Corning pH meter was used for determining the pH of wastewater samples. The limit of accuracy for this instrument was given as 0.1 pH unit with possible interference from high levels of dissolved salts, oil, and fine particles. Of course, pH gives an indication of the acidity or basicity of a water sample; neutral samples are generally considered in the pH range of 5.5 to 8.5.

(8) TOTAL COLIFORM BACTERIA

Total coliform bacteria is done by the membrane filter techniques as set forth in "Standard Methods", Section 408A. Disposable pre-sterilized pipettes and petri dishes were used as well as Erds broth for growing the cultures. Enrichment (as used for drinking quality water) was not necessary due to the high levels of coliform bacteria in the wastewater samples. Total coliform bacteria serve as an indicator of wastewater contamination by microorganisms.

Oil and grease, total organic carbon and metals (by emission spectroscopy) in wastewater samples were determined by the Edison Industrial Waste Treatment Research Laboratory of the U. S. Environmental Protection Agency. Since these analyses necessarily involved sample preparation and shipment from Duluth, Minnesota, to Edison, New Jersey, care was taken in selecting particular samples for analysis. Analyses were generally in conformance to "Methods for Chemical Analysis of Water and Wastes, 1971" by the

Enviromental Protection Agency. Descriptions of the tests are as follows:

(1) TOTAL ORGANIC CARBON (TOC)

TOC is determined by catalytic combustion of a micro sample of wastewater followed by infrared analysis for CO_2. Such an analysis provides a much better indicator of contained organics than does volatile suspended solids. Comparison with analyses for oil and grease then permits assessment of "biological" contamination. Typical precision is $\pm$ 8% at 100 mg/l.

(2) OIL AND GREASE

Oil analyses were run during the study by hexane Soxhlet extraction at low pH followed by evaporation and weighing of the residue. The procedure essentially defines greases and oils. EPA's method can be used for a concentration range of 5 to 1000 mg/l; for higher concentrations (as were often encountered during the study) volumetric techniques are used. Precision and accuracy data are not available.

(3) METALS BY EMISSION SPECTROSCOPY

Emission spectroscopy permits the simultaneous determination of a large number of metals (27 for the 8 samples analyzed in this study) in a micro sample. Briefly, the constituents of a sample are ionized in a flame; upon returning to their ground state, each metal emits characteristic radiation. A spectral scan of the emissions combined with standard emission data permits quantification of the metals in wastewater samples. The resulting concentrations can then be used to determine whether or not metals are present in toxic or unusual amounts.

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